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Studying the Effect of Corrosion on Adhesion Force in Reinforced Concrete Structures

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Abstract: *This adhesion force depends on many factors such as quality of concrete, quality of reinforcement, in which surface properties of reinforcement are important factors.When the reinforcement has not been rusted, the adhesion force between the concrete and the reinforcement is very good, ensuring that they work together. In contrast, when the reinforcement is rusted (due to corrosion), it can greatly affect the adhesion force between the concrete and the reinforcement, and thus greatly affect the simultaneous working of these two materials. Corrosion of reinforcement is really a danger that always threatens the life of structures. The authors conducted experiments on steel rusted to grades I, II, III, IV by alternately dipping in high-concentration brine and exposing it to humid air for 14 days.The samples denoted MI, MII, MIII, MIV correspond to the reinforced concrete test samples with a rust degree of I, II, III, IV. Based on the research results, it can be concluded that the use of clean reinforcement (type I) will not affect the adhesion force between the reinforcement and concrete over time. Type II stainless steel has a slight influence on the adhesion force. Grade III rust can significantly reduce the adhesion between reinforcement and concrete over time. Sample IV has the phenomenon of reducing adhesion force after 30 days tends to happen faster and stronger than sample MIII.*

Keywords: *Adhesion forces, corrosion of reinforcement, steel rust, quality of reinforcement, reinforced concrete.*

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I. INTRODUCTION

Reinforced concrete is a building material made up of a combination of concrete and reinforcement, which are two materials with different mechanical properties. Concrete is a brittle material with relatively good compressive strength but poor tensile strength and is prone to cracking. Reinforced steel is a flexible material with high elasticity, good tensile , and compressive strength. The reinforcement placed in the concrete is mainly used to bear the tensile force instead of the concrete, preventing the development of cracks in the concrete. In addition, reinforcement is also used for compressive purposes along with concrete. Between concrete and reinforcement, there is no chemical reaction , concrete has the effect of protecting the reinforcement from corrosion. Reinforcement and concrete work together mainly because of the adhesion force between these two materials, and their coefficients of thermal expansion are approximately the same.This adhesion force depends on many factors such as quality of concrete, quality of reinforcement, in which surface properties of reinforcement are important factors. When the reinforcement has not been rusted, the adhesion force between the concrete and the reinforcement is very good, ensuring that they work together. But when the reinforcement is rusted, it can greatly affect the adhesion force between the concrete and the reinforcement, and thus greatly affect the simultaneous working of these two materials. In today's construction works, almost all materials made of steel or reinforced concrete are used quite commonly. Many works are degraded and damaged due to the influence of the surrounding environment, reducing the quality of construction works. Which, corrosion of reinforcement damaging reinforced concrete structures is a fairly common problem in construction, especially constructions subject to erosion of the marine environment.In the marine environment, due to hot and humid climate conditions, containing a very high concentration of Cl- ions, reinforced concrete structures are corroded and destroyed very quickly, especially in areas with up and down water and coastal areas.

The rate of corrosion that damages buildings is quite fast, some works with a lifespan of more than 30 years have been severely damaged after 20-25 years of use, even after 10-15 years of use. The cost for repair and remedial work accounts for 30 - 70% of the construction investment. In the aggressive environment, the phenomenon of corrosion of reinforcement and concrete leads to cracking and destruction of reinforced concrete structures, prematurely damaged reinforced concrete structures, which does not guarantee the life of the work. The actual durability of reinforced concrete structures depends on the degree of cavitation and the quality of the materials used. The general opinion on anti-corrosion for reinforced concrete structures is: protect concrete, take concrete to protect reinforcement. That requires measures to prevent and limit the corrosion of concrete and reinforced concrete structures.

Corrosion of reinforcement is a very common and common phenomenon in a hot and humid climate in Vietnam. In places where steel is used, almost all corrosion of steel reinforcement occurs at different levels. Corrosion of reinforcement is a danger that always threatens the life of structures such as wharves, road bridges, drilling rigs, cold towers of nuclear power plants, structures of chemical plants, constructions coastal programs. When the reinforcement is corroded, it has a double effect on the mechanical behavior of the structure: reducing the bearing capacity because the reinforcement area is reduced compared to the original layout; reduces the stiffness of the structure by reducing the area of reinforcement and reducing the adhesive force between the concrete and the reinforcement; reduce deflection when the structure is damaged.

II. METHODOLOGY

2.1 Effect of corrosion of reinforcement on construction works

Corrosion of reinforcement in concrete is a common phenomenon for construction works. The product of the steel rust corrosion process has a large volume, causing swelling, stress, and breaking the concrete layer.

Figure 1. Corrosion of reinforced concrete beams

The survey results show that although the steel in the concrete is protected by the concrete layers, it is still rapidly corroded over time due to the impact of the aggressive environment.

Figure 2. Steel corroded despite the protection of concrete

Steel rust is also one of the main causes leading to the early destruction of steel and reinforced concrete structures, especially for constructions near strong cavitation areas. With unprotected steel structures, after 1 year of testing, it was found that depending on the environment in general, the amount of steel lost from 500 to 2000g/m^2. In addition, they reduce the adhesion force between the steel and the protective coating and cause point corrosion. That leads to loss of the protective ability of the outer coatings. The main effect of steel rust in reinforced concrete is to reduce adhesion forces and increase the risk of premature corrosion and rapid destruction of reinforcement over time. They affect the bearing capacity of the structure and gradually destroy the structure.

2.2 *Materials and test methods*

Material:

Hoang Thach PCB 30 Cement meets the requirements of TCVN 2682:2009.

The size of yellow sand is 2.5, meeting the requirements of standard TCVN 9205-2012- Crushed sand for concrete and mortar.

Crushed stone Dmax=20, meeting the requirements of the standard TCVN 7570:2006- Aggregates for concrete and mortar. Technical requirements.

Water for concrete mixing meets the requirements of TCVN 4506-2012 - Water for mixing concrete and mortar - Technical requirements

Thai Nguyen steel ϕ18 has burrs, cut into pieces with a length of 1000mm.

The steel is rusted to grades I, II, III, IV by alternately dipping in the high concentration of brine and leaving it in humid air for 14 days.

The compressive strength of concreteB45, ratio X:C:D=1:1.75:2.32 (X=438Kg) N/X=0.4, HS=10-12cm, R_{28}=25 MPa.

Experiment: The experiment used 40 groups of reinforced concrete samples (10 samples each) fabricated and maintained according to TCVN 9340-2012, cube molds with dimensions of 150x150x150mm.

The sample sets with symbols MI, MII, MIII, MIV correspond to reinforced concrete samples with rust levels of I, II, III, IV.

Fabrication of test specimens: In order to obtain the design strength of concrete (25Mpa), we must proceed to cast a strength test specimen. The test piece here is a cylindrical sample with dxh=150(mm)x300(mm).

Prepare material:

Stone meets standard TCVN 7570:2006- Aggregates for concrete and mortar. Technical requirements. The stone must be sieved and classified into different sizes (Dmax=20mm...), then it must be washed to remove impurities such as garbage, dry humus, stone powder... The sand must be clean enough and not mixed with mud and clay, and the number of organic impurities according to TCVN 9205:2012- Crushed sand for concrete and mortar. The cement must ensure no lumps, fineness, and other criteria comply with TCVN 2682-2020.

Carrying out casting concrete samples:

Before pouring concrete, we need to check the mold, clean the surface and apply anti-stick agent on the surface, make sure that the mold is hard enough, firm and have the correct dimensions. The inside of the mold must be flat, with no protrusions exceeding 80 micrometers. After completing the preparation stages, we begin to pour concrete. We divide the concrete mixture into the mold into 3 layers. Then we use a steel bar ϕ 18 with a length of about 50cm to poke evenly into each layer. The first layer we poked close to the bottom, the second layer poked close to the first layer, and so on until the last layer. After that, we put the mold on the vibrating table, until the large air bubbles escape, then we use a trowel to remove the excess and smooth the surface of the sample. After pouring concrete, after about 24h-48h, we can remove the mold and cure the sample at a temperature of 28±2^{o}C and the humidity is from 80-100% until the day of sample testing.

The compressive strength is calculated according to the formula:

$$R_n = k\,\frac{P}{F} \tag{1}$$

In there:

P: Sample failure load

F : Area of compressive force of the sample

K: Conversion factor (k=1.2 for a 150x300 cylinder).

The test results have:$R_n = k\,\frac{P}{F} = 20(MPa)$

The above result is the strength compared to the proposed design. We begin to cast the combinations of samples MI, MII, MIII, MIV corresponding to the reinforced concrete samples used with rust levels of types I, II, III, IV. The sequence is similar to the process of casting test specimens according to the experimental ages of 20, 30, 40, 50, 60 days. Process of compressing test pieces to determine design strength.

Test run:

The adhesion force between reinforcement and concrete was tested at the age of 20, 30, 40, 50, 60 days at the construction laboratory of Thai Nguyen Design Joint Stock Company. When pulling, the axis of reinforcement coincides with the axis of the tractor, load at a rate of 500N/s until the reinforcement slides completely from the concrete**.**

$$\tau_{max} = \frac{P_{max}}{l\pi d}\ (N/mm^2) \tag{2}$$

In there:
τ_{max} -Strength of adhesion force between reinforcement and concrete, N/ mm^2.
P_{max} -Maximum tensile force when the reinforcement is completely slipped from the concrete, N
l-Length of reinforcement in concrete, mm
d - Diameter of reinforcement, mm

III. EXPERIMENTAL RESULTS

3.1. Calculation by theoretical formula

MI, MII, MIII, MIV are reinforced concrete samples with grade I, II, III, IV rust. The experimental results of the influence of steel rust on the adhesion force between concrete and reinforcement are presented on the table and the graph:

Table 1. Research results on the influence of steel rust on the adhesion force between reinforcement and concrete

Numerical order	Sample symbol	Adhesion strength between reinforcement and concrete				
		20 days	30 days	40 days	50 days	60 days
1	MI	12.6	12.7	12.8	12.9	12.9
2	MII	12.5	12.65	12.7	12.75	12.8
3	MIII	12.7	12.75	12.7	12.5	12.2
4	MIV	13	13.2	12.8	12.2	11.6

Note: MI, MII, MIII, MIV are reinforced concrete samples with grade I, II, III, IV rust.

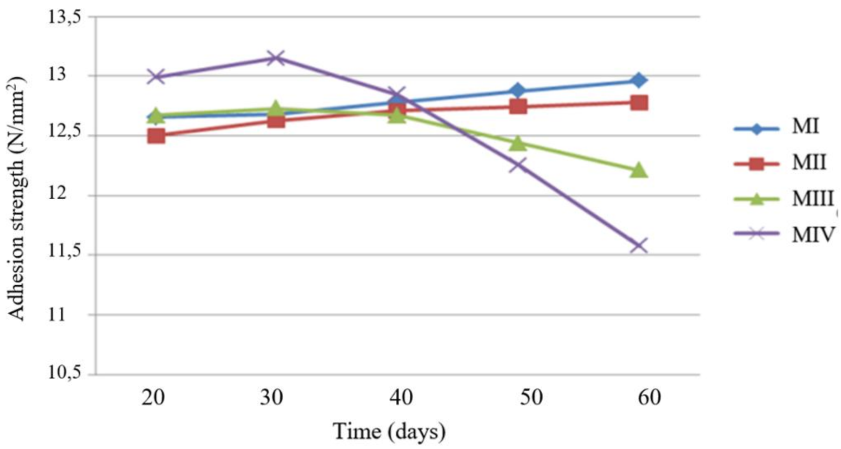

Figure 3. Graph showing the effect of rust on the adhesion force between concrete and reinforcement

For samples with MI: According to the test results at the sample age from 20 to 60 days, when using unrusted reinforcement, the adhesion force of the reinforcement and concrete tends to increase gradually over time. For example, the adhesion force at the age of 60 days compared with the age of 20 days is about 2,98 %. This phenomenon can be explained by the development of concrete strength and increase of concrete strength over time under good curing conditions. Based on the research results, it can be concluded that the use of clean reinforcement (type I) will not affect the adhesion force between the reinforcement and concrete over time.

For samples with the MII symbol: The adhesion force between reinforcement and concrete also tends to increase gradually over time, but at the same experimental age, all values are lower than that of MI samples. The reason for the increase in adhesion force with time can be explained as the above MI samples. The reason why the adhesion force is slightly lower at the same age compared to the MI sample may be due to the influence of type II steel rust. Thus, grade II stainless steel has a slight influence on the adhesion force.

For sample symbol MIII: In the range of experimental age ranges, the adhesion force between reinforcement and concrete increases to 30 days of age, then the adhesion force tends to decrease markedly. In which, at the age of 20 and 30 days, the adhesion force of the MIII sample was higher than that of the MI sample. In the 40s, 50s, and 60s, that steady drop is worrisome. The phenomenon of increased adhesion force of the MIII samples compared with the MI samples at the first 30 days was due to the use of grade III stainless steel. There are rust spots on the steel surface that are relatively firmly attached to the steel surface and have not been lost in the concrete environment. These scaly rust spots also can adhere firmly to the concrete, so on the one hand, they increase the contact area of the reinforcement with the concrete, on the other hand, they also create friction to resist the sliding force.

Moreover, in the formula when calculating the adhesion force, the reinforcement surface is considered to be completely smooth without considering the convexity caused by the steel scale. As long as the scale is firmly attached to the steel surface, the scale will have the same effect as the steel spikes that can increase the adhesion force between the concrete and the reinforcement. The phenomenon of reducing the adhesion force of the MIII sample at 30 days is due to the rust scale is gradually separated from the steel surface. Because reinforcement corrosion tends to develop continuously over time. The more rust flakes are removed, the smaller the contact area of the concrete and the reinforcement, so the adhesion force is continuously reduced. From this study, it is shown that reinforcement with grade III rust can significantly reduce the adhesion force between reinforcement and concrete over time.

For the MIV sample: there is an increase and decrease in the adhesion force between the reinforcement and the concrete similar to that of the MIII sample. The only difference is that the first 30 days are higher than the MIII model. This can be explained by the fact that the grade IV rust reinforcement has a lot of thick scale rust that produces more spikes than the MIII model. Therefore, it has the effect of increasing the adhesion force in the early stages but causing worse consequences in the later time. In particular, it tends to decrease the adhesion force after 30 days and occurs faster and stronger than the MIII sample.

IV. CONCLUSION

Grade I steel rust (not rusted or very lightly rusted) does not adversely affect the adhesion force between reinforcement and concrete.

Type II steel rust has an effect on the adhesion force between reinforcement and concrete but has not caused a decrease in adhesion force overtime.

Grades III and IV have a large influence on the bond strength between reinforcement and concrete, which tends to increase adhesion forces for a period up to the first 30 days. After that, the adhesion force tends to decrease continuously. The degree of influence of steel rust on the adhesion force is ranked in ascending order from rust type II to rust type IV. In which, type IV rust has the most serious impact.

Conflict of interest

There is no conflict to disclose.

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REFERENCES

[1]. Cao Duy Tien, Pham Van Khoan, Le Quang Hung and collaborators, “Summarization report of the economic-technical project against corrosion and protection of concrete and reinforced concrete structures in the sea area", Institute of Construction Science and Technology, November 2003.

[2]. Nguyen Cong Thang (2016), Research on manufacturing super high quality concrete using mineral additives and materials available in Vietnam, PhD thesis, University of Civil Engineering, Hanoi.

[3]. Pham Van Khoan, Tran Nam, "Solutions for anti-corrosion and protection of rebar under the impact of chlorine cavitation in the environment", Journal of Construction Science and Technology 2004.

[4]. Truong Hoai Chinh, Huynh Quyen, Tran Van Quang, Nguyen Phan; “Synthesize, analyze, evaluate and forecast the current state of cavitation and erosion of civil and industrial constructions in the coastal area of Da Nang”- Scientific research project at Da Nang city level, 11/2007.

[5]. Standard TCVN 2682:2009 Portland cement - Technical requirements

[6]. Standard TCVN 9205-2012Crushed sand for concrete and mortar

[7]. Standard TCVN 7570:2006Aggregates for concrete and mortar. Technical requirements.

[8]. StandardTCVN 4506-2012 Water for mixing concrete and mortar - Technical requirements

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